ELM – Simulating Plasma Gun Proposal

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Overview

- Need for a ELM-Simulating Plasma gun
- Design and Initial Results
  - Helicon, Pre-ionization Source Plasma
  - Pulse Forming Network (PFN)
  - How to merge pulses into an ELM
- Planned Diagnostics
- Budget Needs

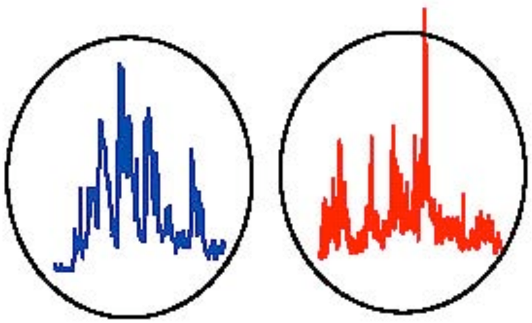
Motivation

- Why study ELMs?
  - Limiting heat flux for divertor surfaces
  - Largest cause of divertor erosion and impurity production
  - How effective is “vapor / plasma shielding”

- ELM Plasma Material Interactions
  - Test bed for candidate divertor materials
  - Material survivability / erosion / melt layers
  - Surface effects
    - Are there different redeposition rates for mixed materials
    - Changes is surface morphology and composition

Type-I ELM Characteristics

- ELMs emanate from the LCFS
- Higher n_e and T_e at PFC
- An ELM is a series of plasma bursts
  - Each burst is 50 μs
  - Envelope (the ELM) lasts ~1 ms
- Experimental evidence on several machines[1,2]
- High heat flux onto the divertor surface

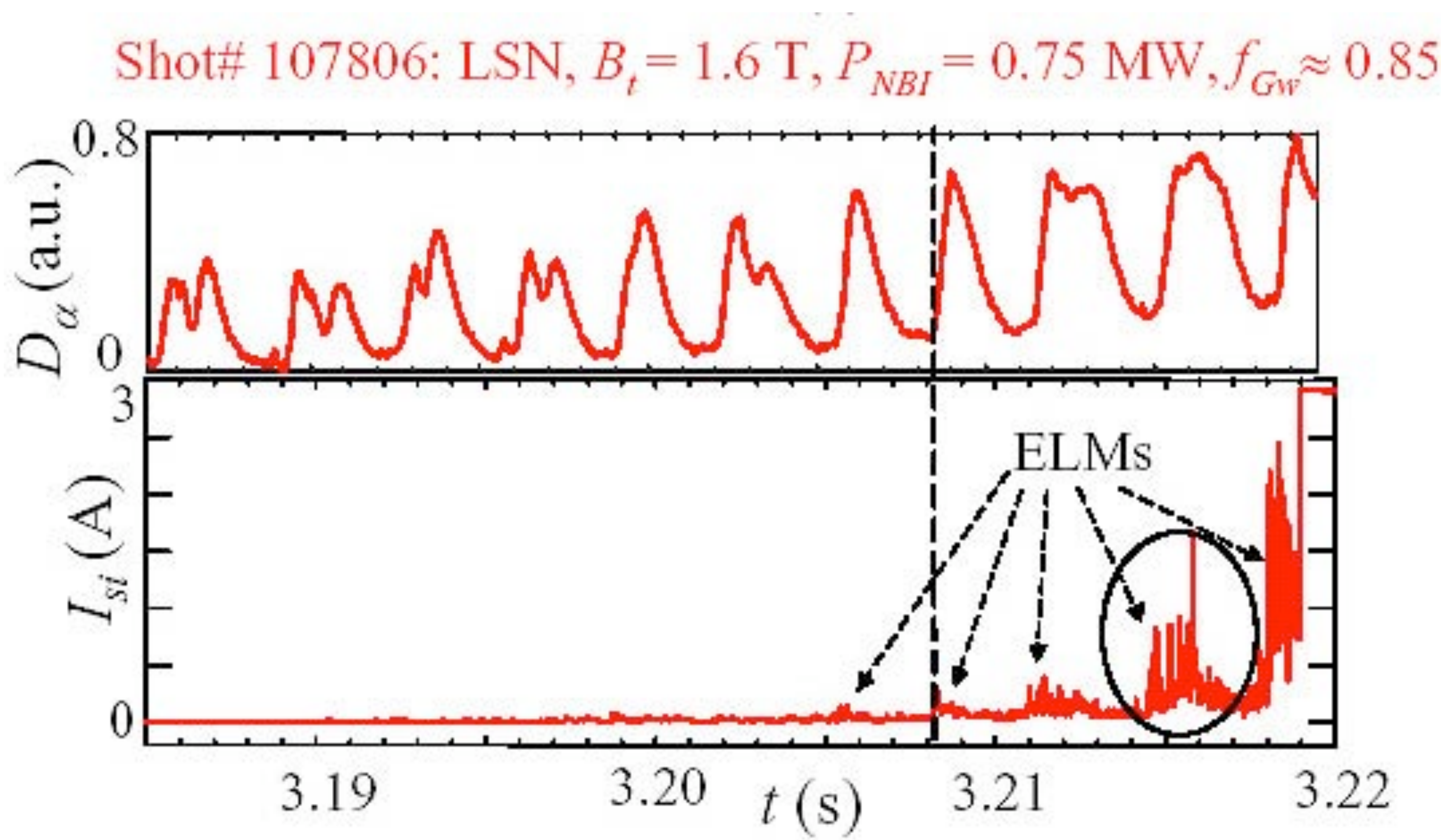


- To the probe ELMs appear as series of spikes rather than a discrete event as on D_α

[1]C. E. Bush, et al., "ELM Physics in NSTX – Onset and Characteristics", NSTX Research Forum, November 28-30, 2001. Reprinted from ALPS 2003 Meeting, Oakbrook IL.

[2]D. Rudakov, "Far SOL and Near-Wall Plasma Studies in DIII-D," ALPS Meeting November 2003, Oakbrook, IL.

D-IIID data showing ELM structure



Design Goals

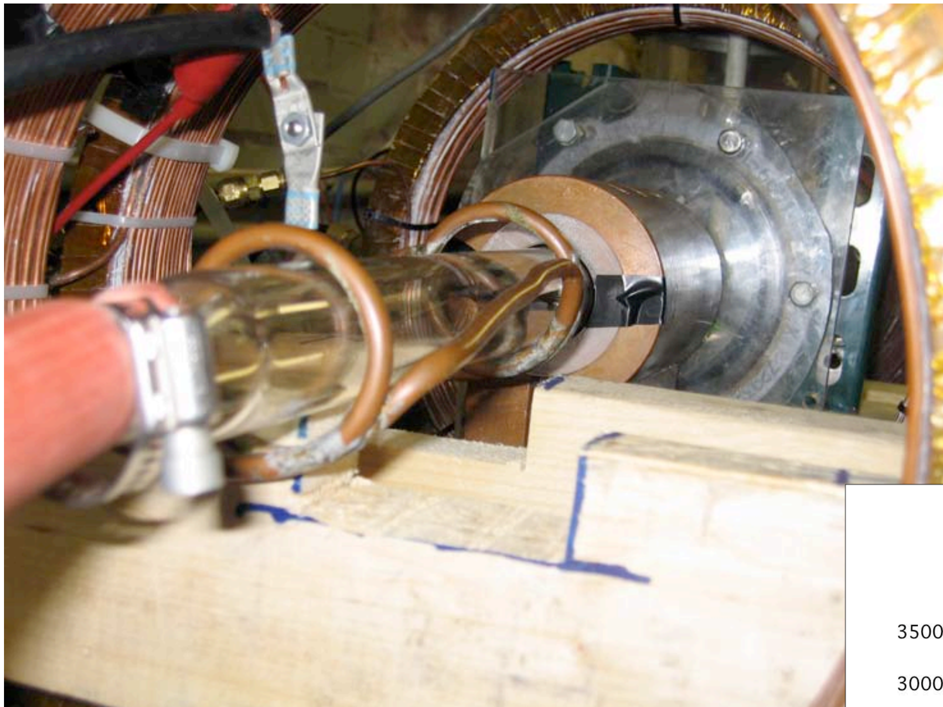
- Comparison of anticipated parameters to NSTX (short term) and ITER (long term) Type-I ELMs

ELM Parameter	ITER	NSTX	UIUC (proposed)
Power Loading	~10 MJ/m^2	< 1 MJ/m^2	1 MJ/m^2
ELM Event Frequency	~1-10 Hz	10-20 Hz	single shot
Total ELM Duration	~0.1-1 ms	~1 ms	~ 0.5 ms
Blob Subfrequency	~10-100 kHz	~10 kHz	~ 10 kHz
Plasma Temperature During ELM (~$T_{pedestal}$)	1-2.5 keV	100 eV	100 eV
Plasma Density During ELM (~$n_{pedestal}$)	~10^{19} m^{-3}	~10^{19} m^{-3}	~10^{19} m^{-3}
Magnetic Field Strength At Divertor (~B_t	~1-5 T	~0.5 T	0.4 T

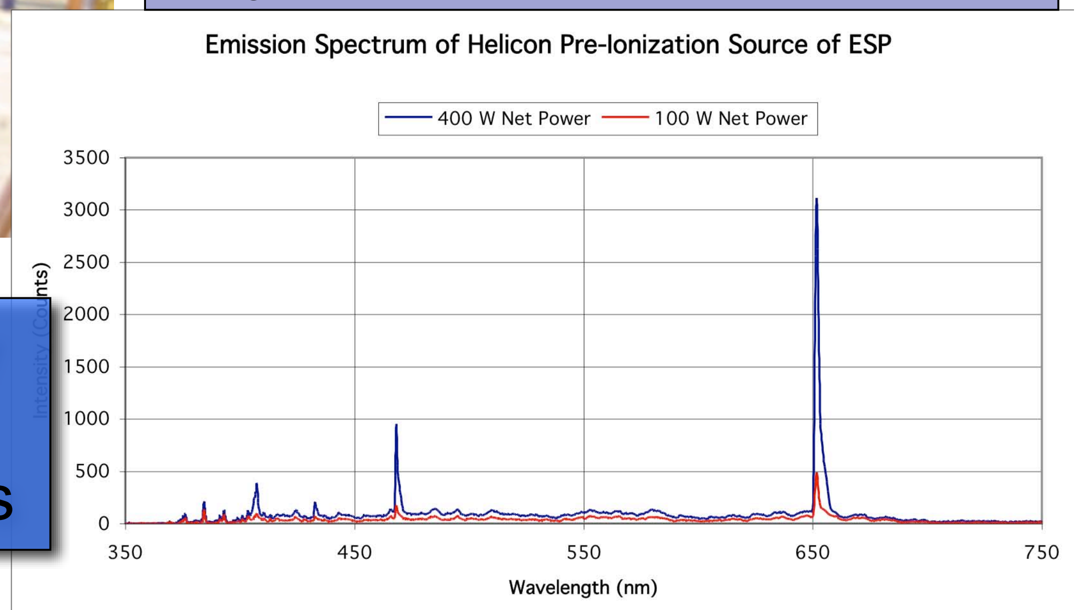
Benefit to US PFC Program

- Domestic experiment directed by US program, relevant to ITER tasks
- Compliments Steady-State Plasma exposure device – **PISCES**
- Compliment Electron-Beam High Heat Flux experiment – **Sandia Albuquerque**
- Provides experimental test-bed for HEIGHTS package – **Argonne Nat. Lab.**

Helicon Source

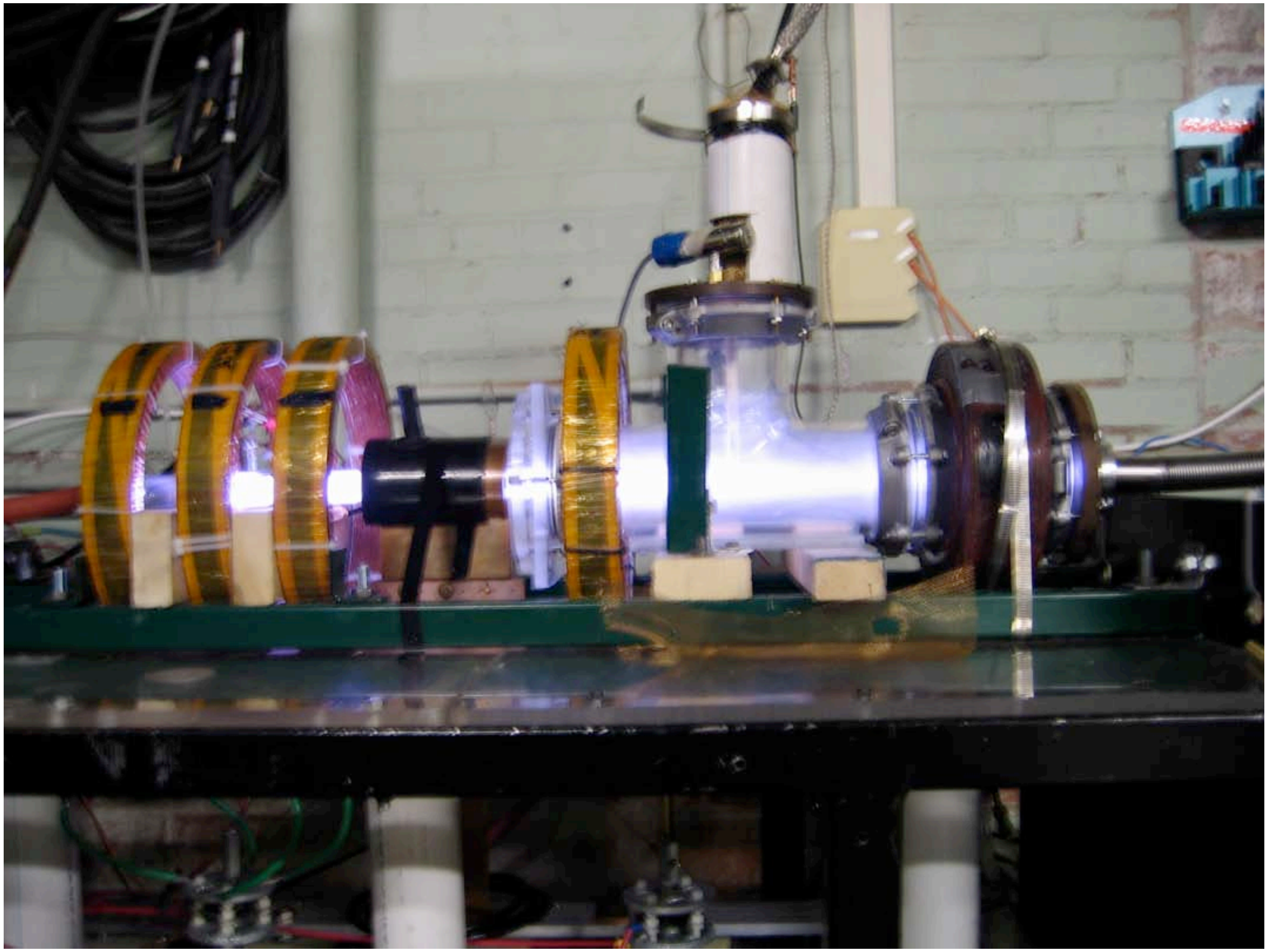


- Pre-ionization Source
- Nagoya Type-III Antenna
- 100 - 250 W RF Power
- 500 Gauss B field at Antenna
- T_e ~ 4-6 eV in the source
- $n_e \sim 10^{19}\ m^{-3}$



Provides a high conductivity plasma!
B Field diffusion time ~ 20 μs

ELM Simulating Plasma Gun Prototype, showing Helicon target plasma



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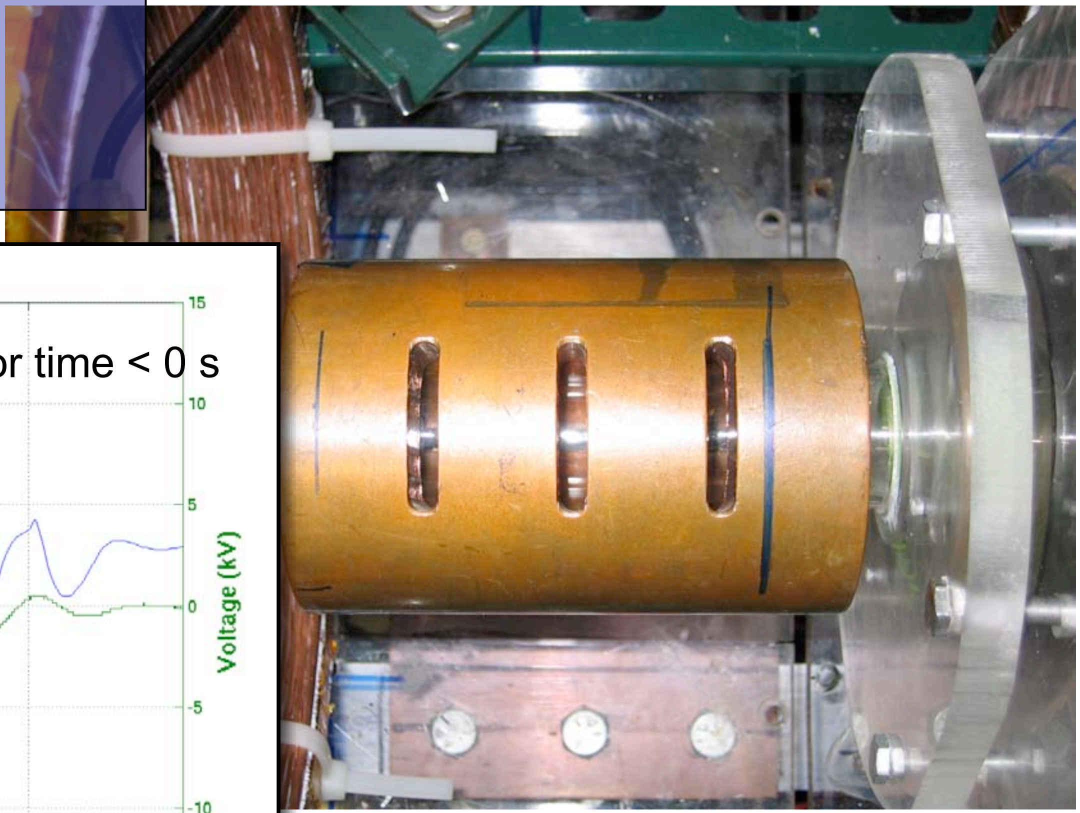
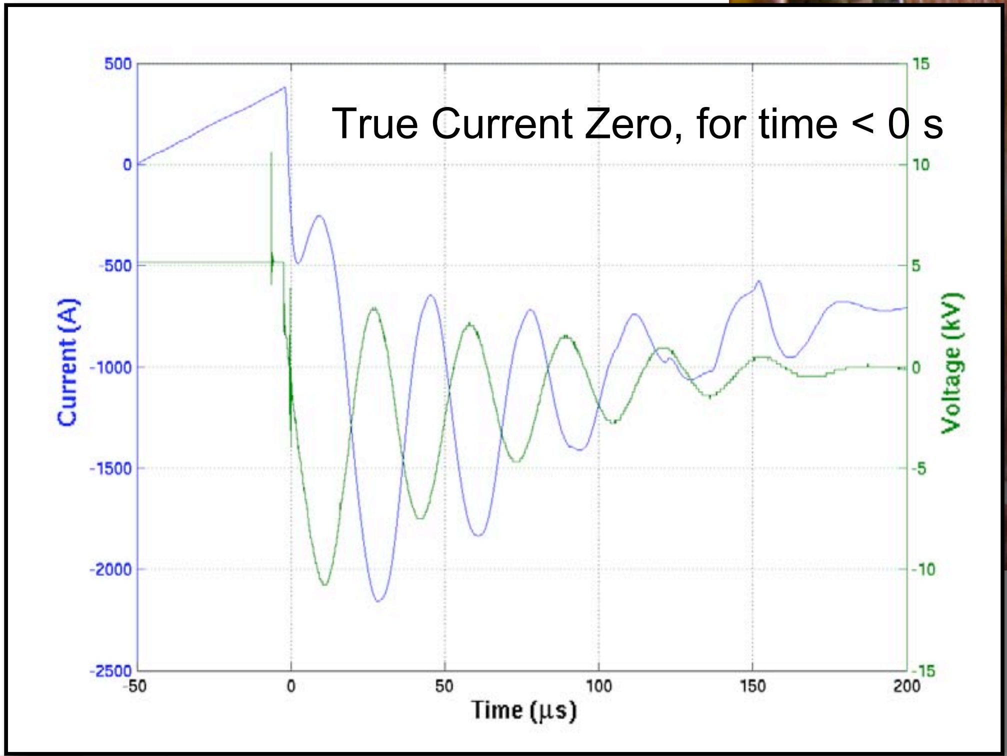
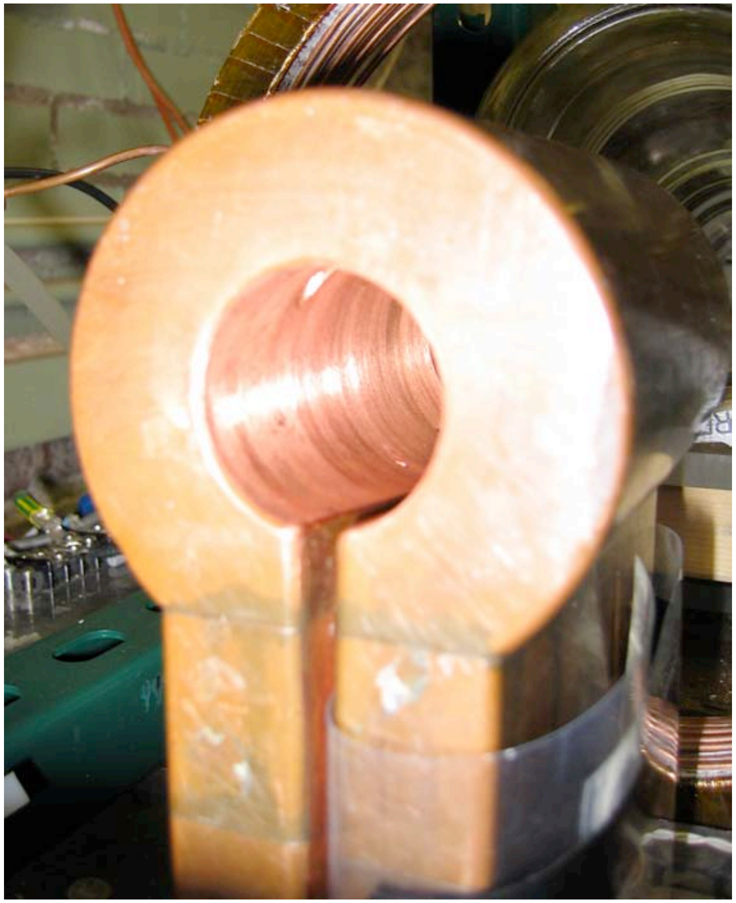
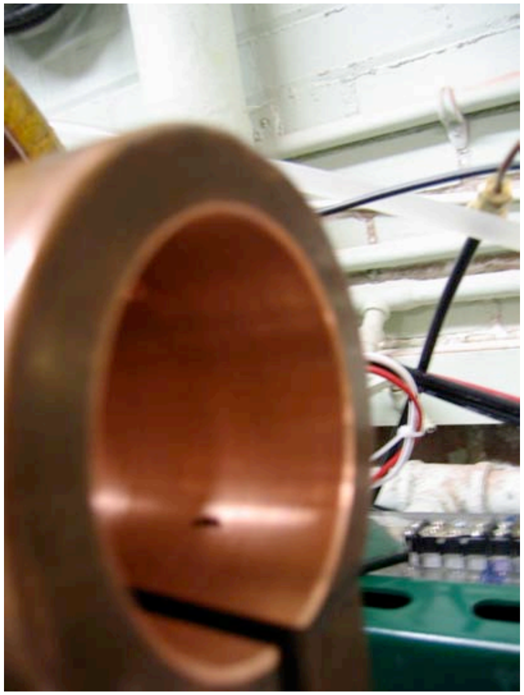
Theta Pinch

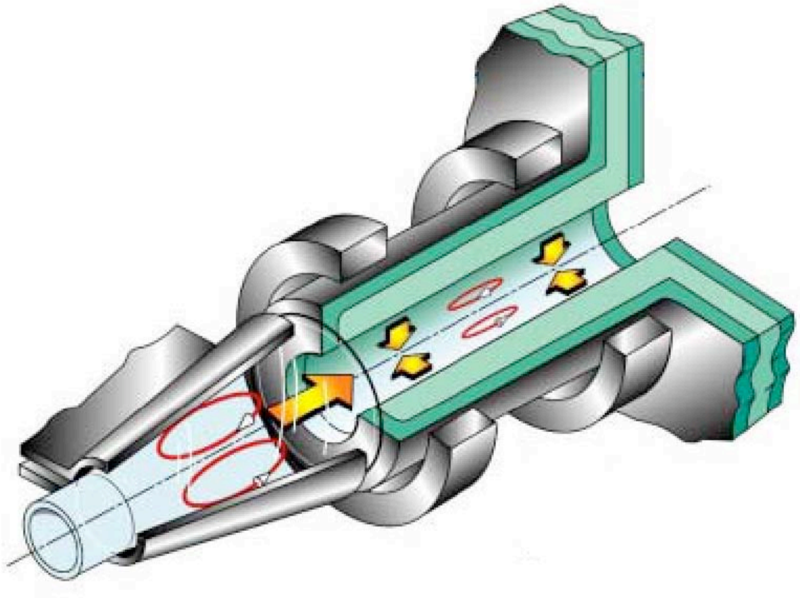
- Single Turn
- $\lambda/4 < 10\ \mu s$
- low inductance





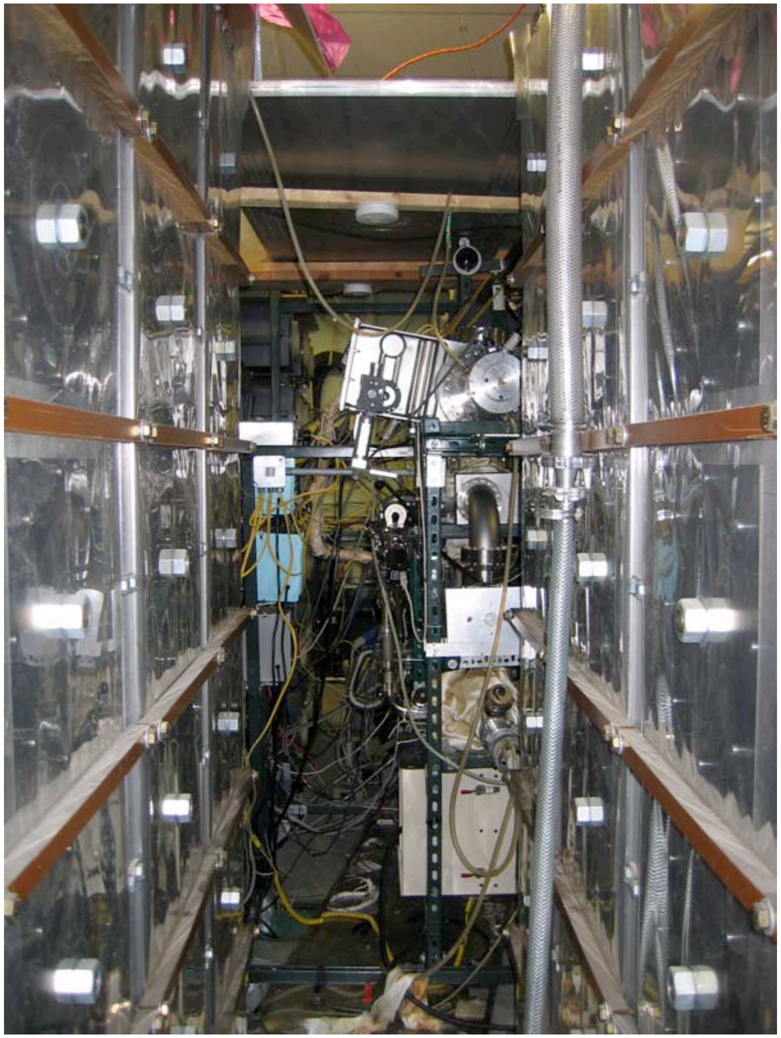




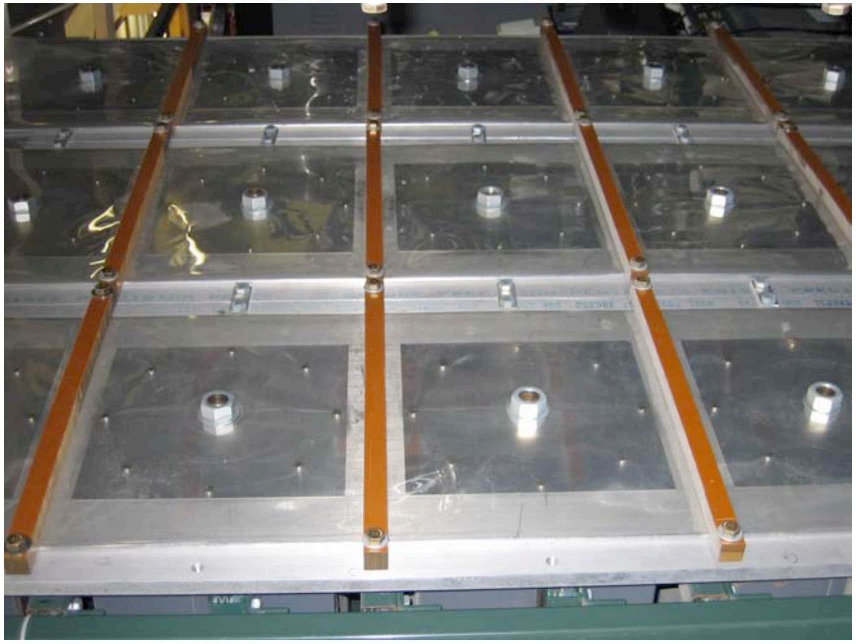


Conical Cross-Section similar to FRC formation / translation

Energy Available

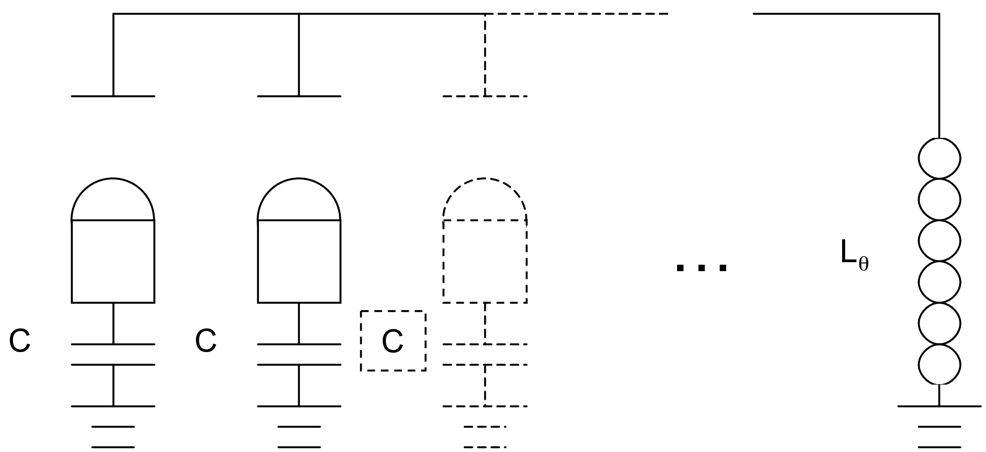


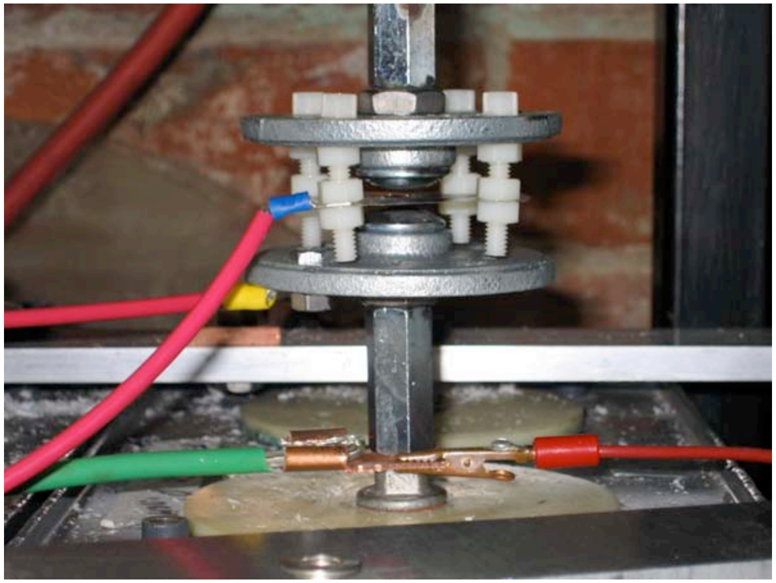
- 250 kJ Capacitor Bank in existence at Illinois of low inductance high voltage



Pulse Forming Network for Multiple Current Pulses

Each Cap, C = 55 μF





- Low cost ($12) spark gap and trigger/delay circuits

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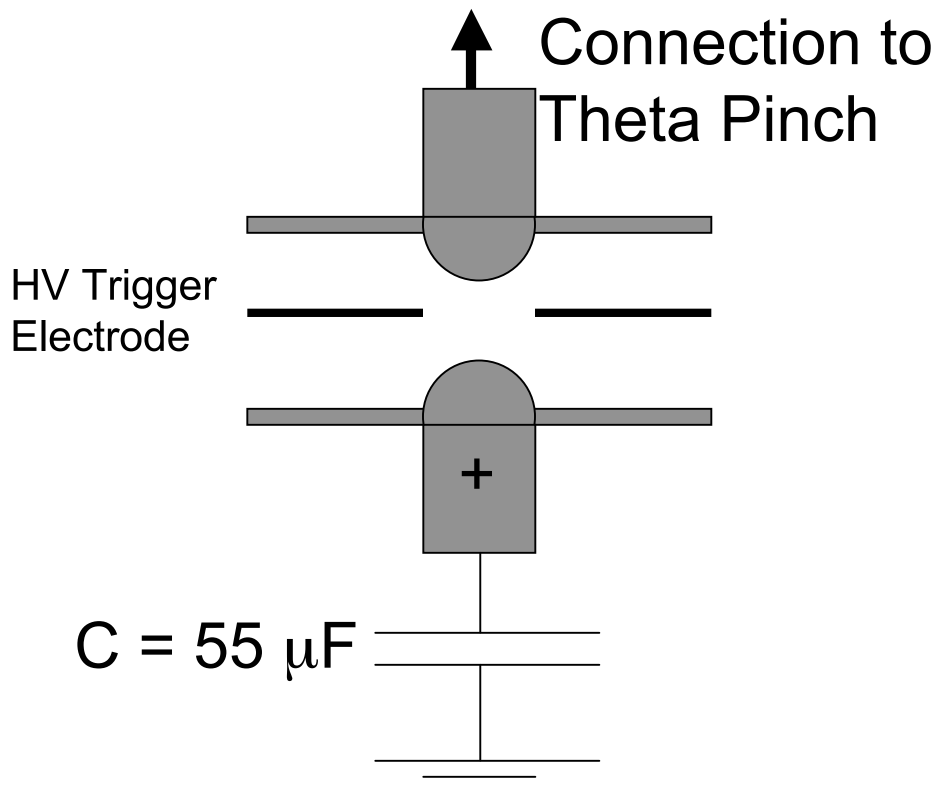
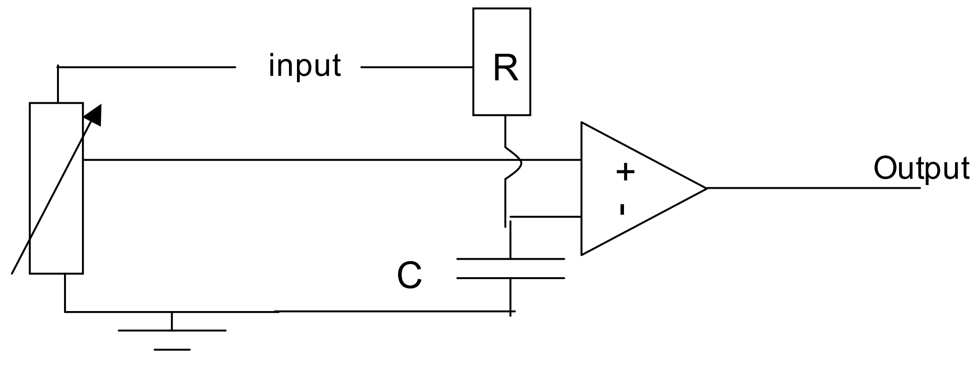
Schematic of Spark Gap Switch



- Directly attached to the Capacitor
- Steel Electrodes
- SS HV Trigger Electrode
  - + 20 kV Trigger signal with ramp time ~ 100 μs
- Carriage bolts and stanchions for use in concrete, and automotive ignition coil

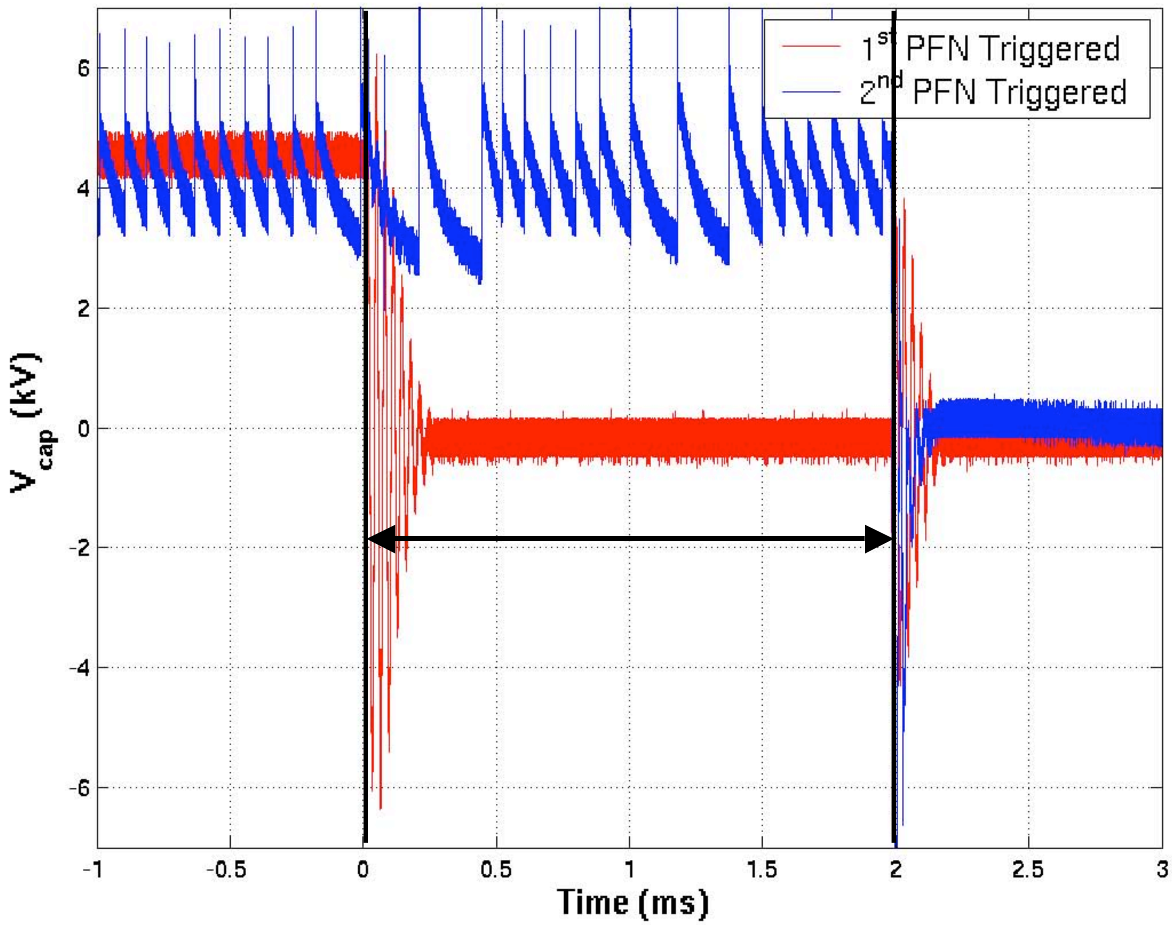
How to create multiple pulses

- Create multiple PFN pulses, all within 1 ms
  - Will create a plasma similar to an ELM
- How do we do this?
  - One trigger signal, many RC delay circuits



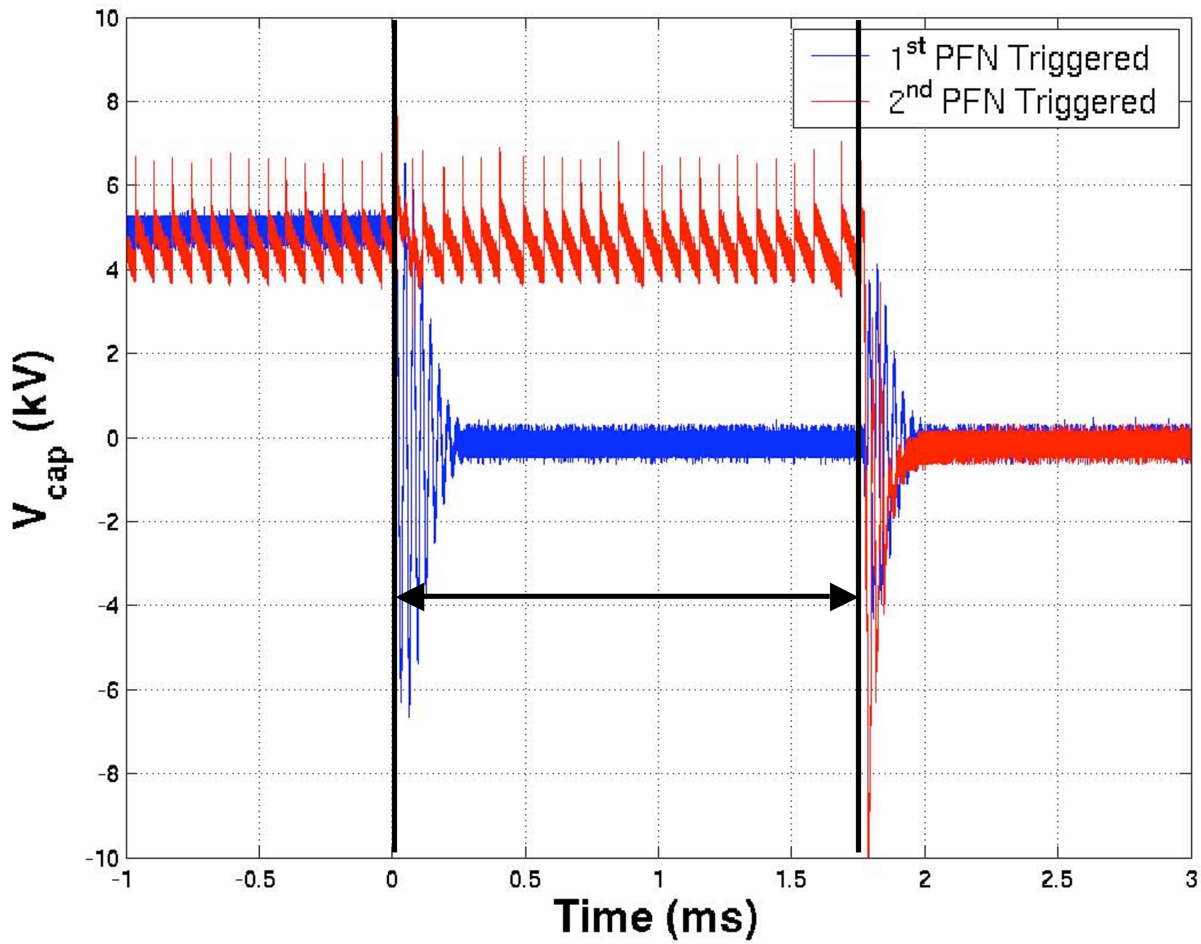
- Can we fire multiple current pulses into a theta pinch coil?

2 ms Delay

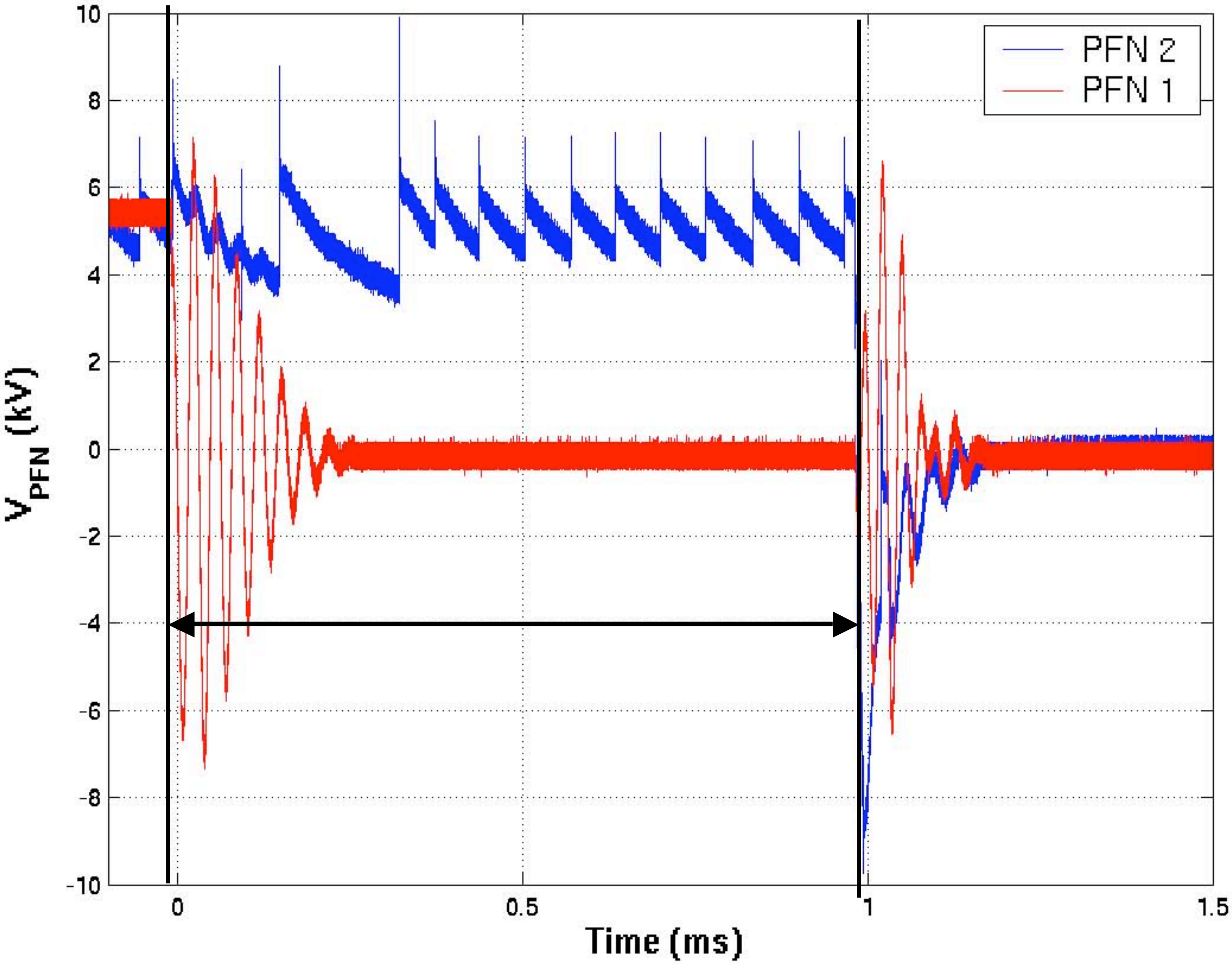


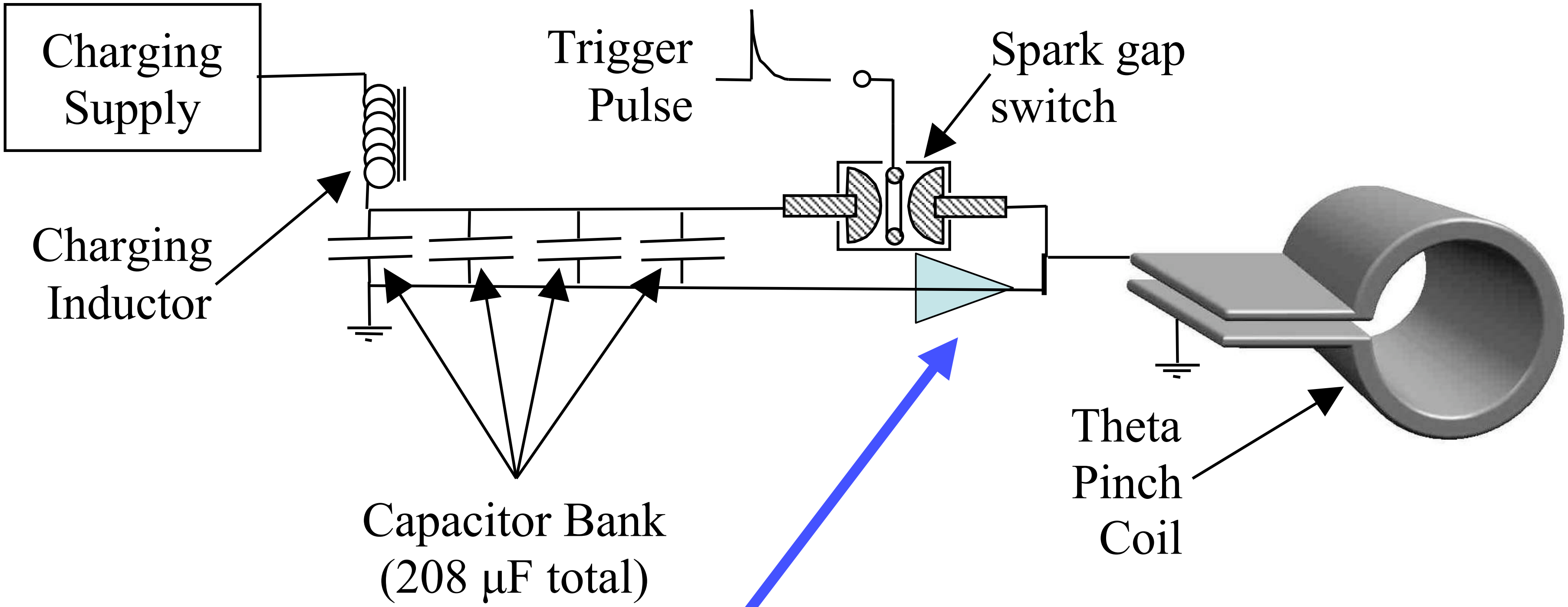
1st PFN Triggered
2nd PFN Triggered
V_{cap} (kV)
Time (ms)
6
4
2
0
-2
-4
-6
-1
-0.5
0
0.5
1
1.5
2
2.5
3

1.75 msec Delay



1 ms Delay





Need high-powered diode to allow trigger from one capacitor group to lie on top of trigger of next capacitor group.

(It is being shipped this week.)

ESP-Gun Features

- Will use pulsed fields to get relevant field strengths – ten times higher than present.

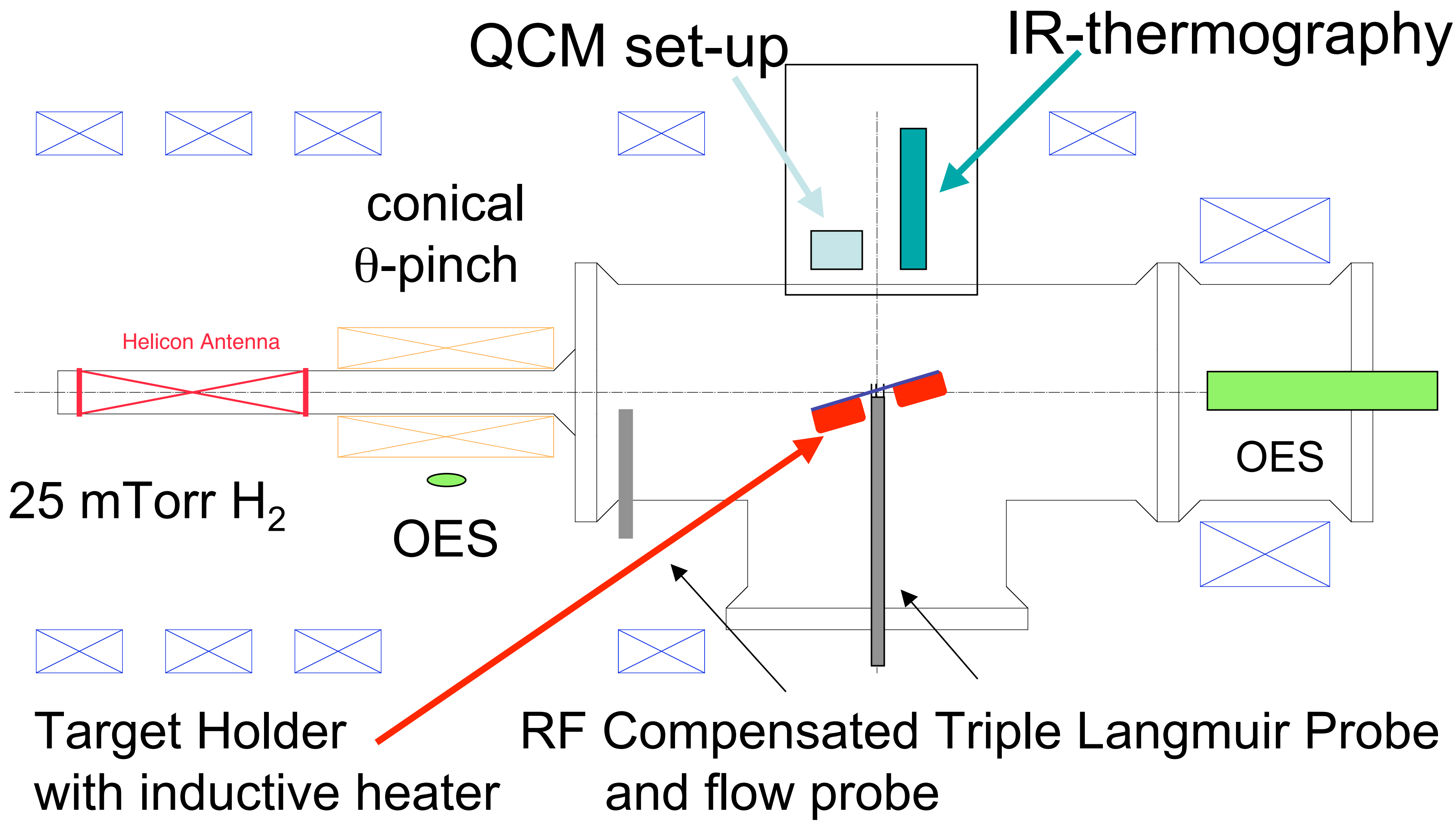
- Target will be at grazing incidence to field and angle can be varied – as in a fusion device.
  - Target bias not used to get energy deposition

- Inductive heater to control initial temperature
  - Plasma not used to control temperature

ESP Gun Diagnostics

- IR thermography of target surface to measure heat flux using fast phototransistors -- will give heat response and energy delivered in combination with thermocouples
- RF compensated triple Langmuir probe – will give time-resolved measurements for electron density and temperature
- Langmuir probe pair along axis to measure plasma blob length and velocity along filed lines
- QCM to measure shot by shot deposition of material eroded from target
- Optical spectroscopy for Hα, Hβ, etc. lines, line broadening for ion temperature.
- Material Research lab Center for Microanalysis – target surface composition and morphology changes

ESP-gun Diagram



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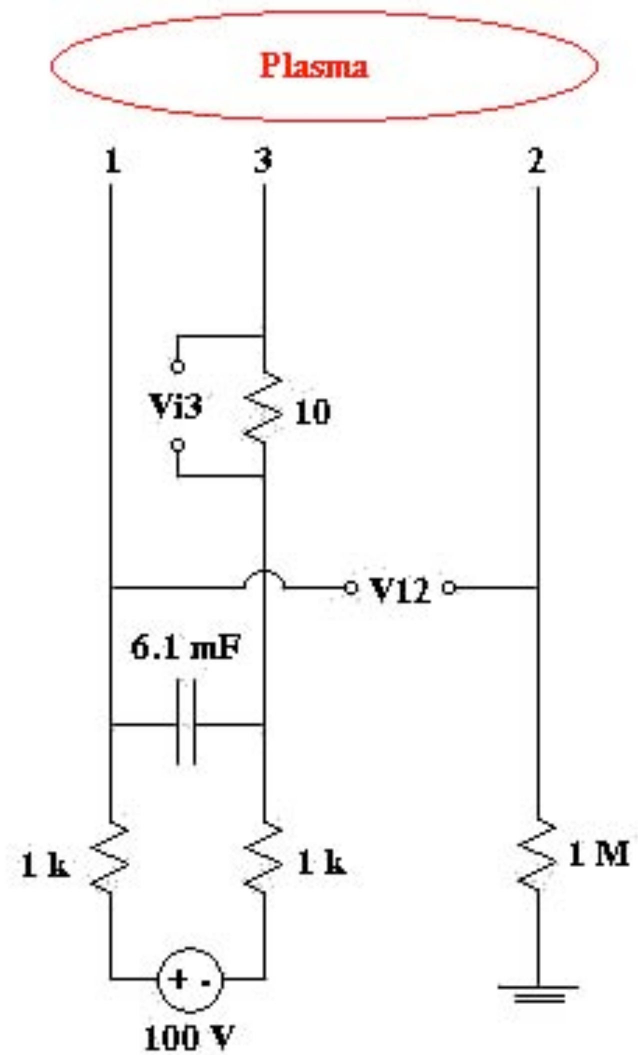
Triple Langmuir Probe

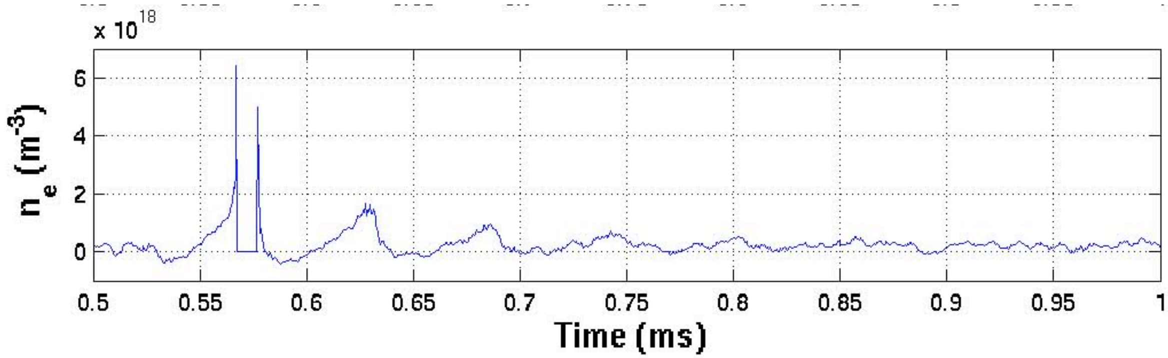
- 3 Probe tips @ Constant Voltage
  - $V_f < V_1 < V_p$
  - $V_2 = V_f$
  - V_3 is in ion sat. (-45 V)
  - Yields T_e and n_e as functions of time

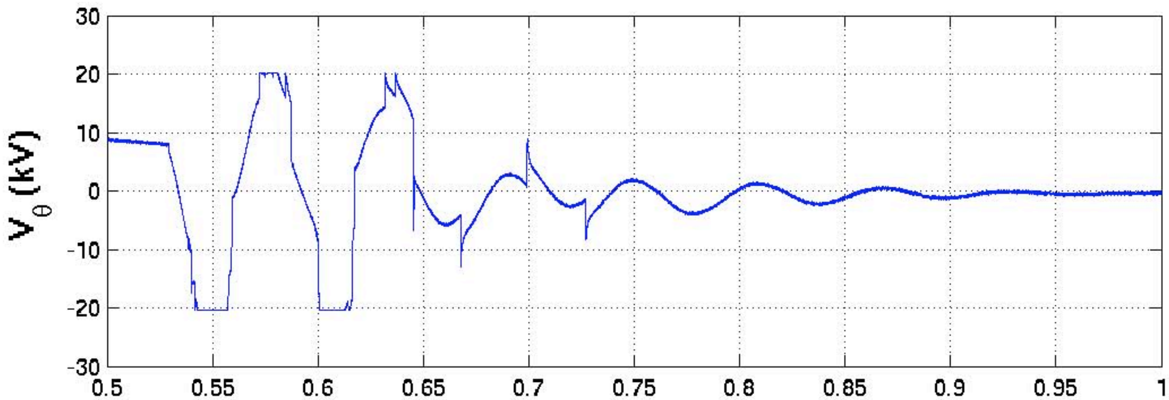


$$kT_e(t) \approx 1.44e\left[V_1(t) - V_2(t)\right]$$

$$n_e(t) = \frac{i_{sat}(t)}{0.61eA_p}\left(\frac{m_i}{kT_e(t)}\right)^{1/2}$$

Voltage on Coil and Density on Target





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Why fund from PFC money ?

- Phase I STTR is in place through Starfire Industries
- Money needed to fund diagnostics to improve chances for phase II proposal, and pay salaries during interim.
- Shows visible vote of confidence to SBIR administration --- (put your money where your mouth is)
- ELM simulating experiment is clear need

Budget

- Personnel
  - One graduate student $ 50,000
- Equipment
  - QCM diagnostic 11,000
  - IR thermography 9,000
  - OES upgrade 10,000

Total $ 80,000

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Personnel Impact

Personnel	actually expense (incl. ICR, travel, M&S, undergrads)	FY 04 PFC funded	FY 05 PFC funding level
Grad: Matt Coventry	60,000	60,000	
Grad: Wes Olczak	60,000	60,000	
0.5 Grad: Ben Masters (other half STTR)	30,000	30,000	
0.5 Grad: Travis Gray (other half STTR)	30,000	30,000	
0.5 Grad: Huatan Qiu	30,000	0	
0.5 Postdoc: Robert Stub bers	50,000	50,000	
One month PI	20,000	0	
Equipment	20,000	23,000	
Total	**300,000**	**253,000**	**223,000**

Summary

- ELMS need more study and simulation
- Initial ESP Gun tests are promising
  - Established a high conductivity, pre-existing plasma with high density.
  - Initial diagnostics show plasma pulses downstream from conical theta pinch
  - Have identified areas to work on – know solutions (only 2 months since initiation of effort)

- **Cost effective** addition to US PFC community with clear ties to multiple groups

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